



Relevant Issues of Carbon Fiber for the Emerging Wind Market

Toray Carbon Fibers America, Inc.
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Sandia Blade Workshop
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Contents

- 1. *Toray Industries and Toray CFA Company Information***
2. CF Forms and Applications
3. CF Technical Issues for the Wind Market
4. CF Commercial Issues for the Wind Market

Summary of Toray Industries, Inc.

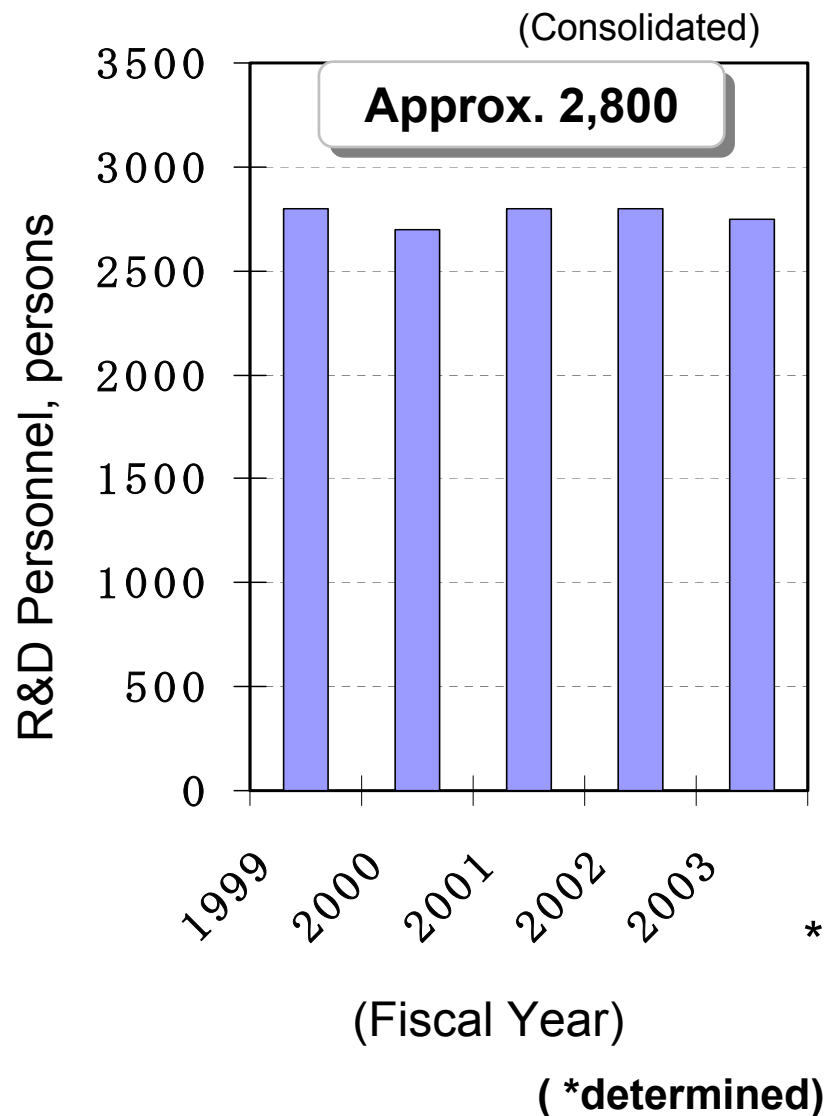
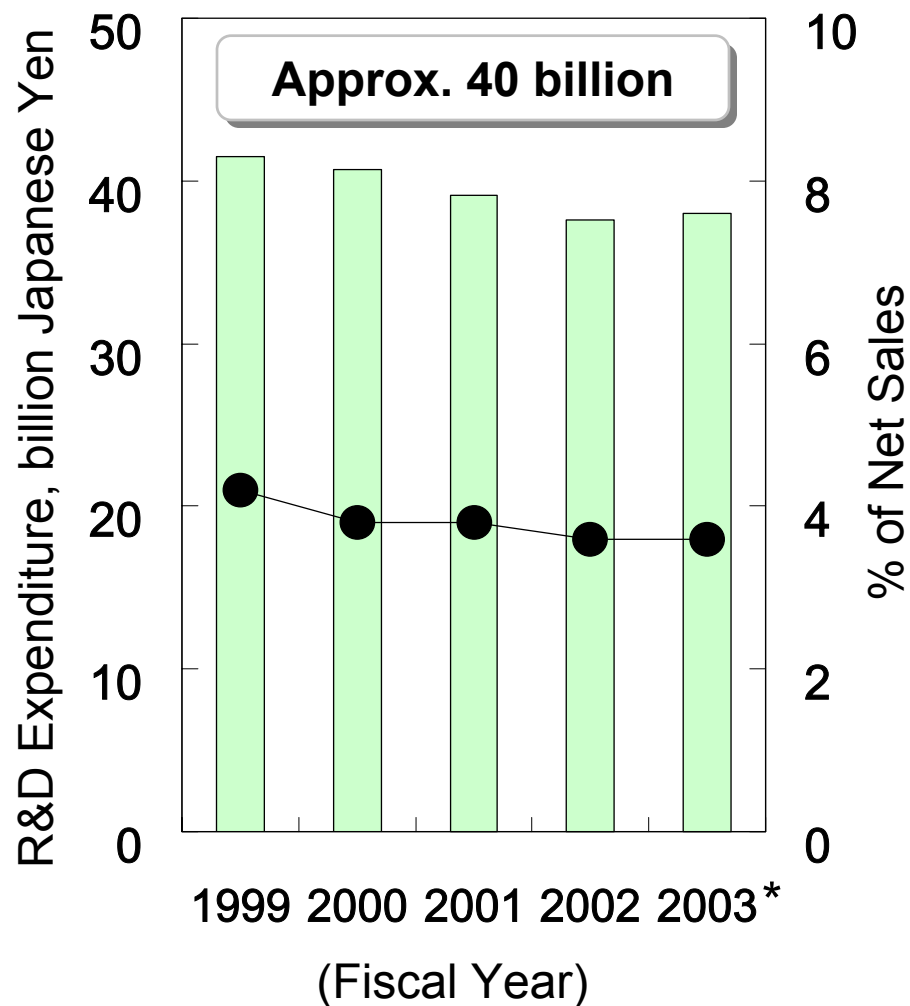
- Founded January, 1926
- Employees 35,700
- Net Sales 1015.7 billion yen (US \$8.2 B)
- Business Domain

Note: As of March 31, 2002 (US\$ 1.0 = 124 yen)

- Fibers and Textiles	39.0%
- Plastics and Chemicals	22.4%
- IT Related Products	13.3%
- Housing and Engineering	13.4%
- Pharmaceuticals & Medical Products	4.5%
- New Products & Other Business*	7.4%

(*Includes Carbon Fiber)

Toray's R&D Focus



Toray's Activities for Advanced Materials

Advanced Materials

Foundation Businesses

**Nano-structured
Materials**

**Environmentally
Friendly Materials**

**New Functional
Materials**

Expanding Businesses (3 Growth Areas)

Information and Telecommunications

**Circuit
Materials**

**Advanced
Display Materials**

**High Performance
Films**

Environment, Safety and Amenity

Composite Materials

Water Treatment

Alternative Energy

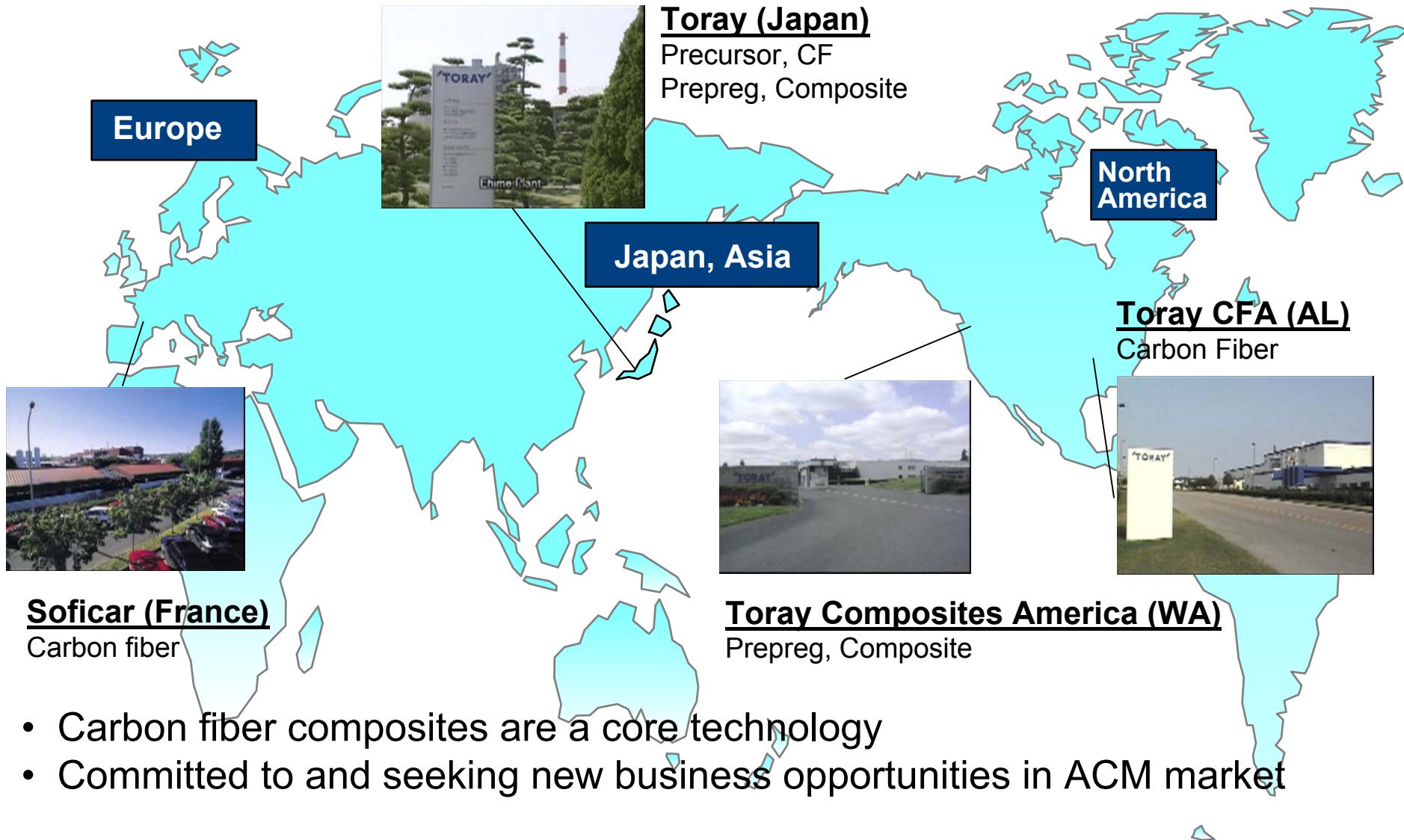
Life Sciences

Drug Discovery

Innovative Therapy

**Bio/Nano-bio
Materials**

ACM Division – TORAYCA Global Operation



- Carbon fiber composites are a core technology
- Committed to and seeking new business opportunities in ACM market

Toray CFA History



- Established May 1997 in Decatur, AL
- First production began April 1999
- 90,000 sq. ft. on 50 acres, approximately 100 employees
- Sales offices in Dallas, LA and Atlanta
- Products manufactured at Decatur plant:
 - Regular and intermediate modulus fibers
 - T600S, T700S, T700G, T800S, M30S, M30G
 - Tow Sizes: 12K, 18K, 24K

Technical Development Focus at Toray ACM Division

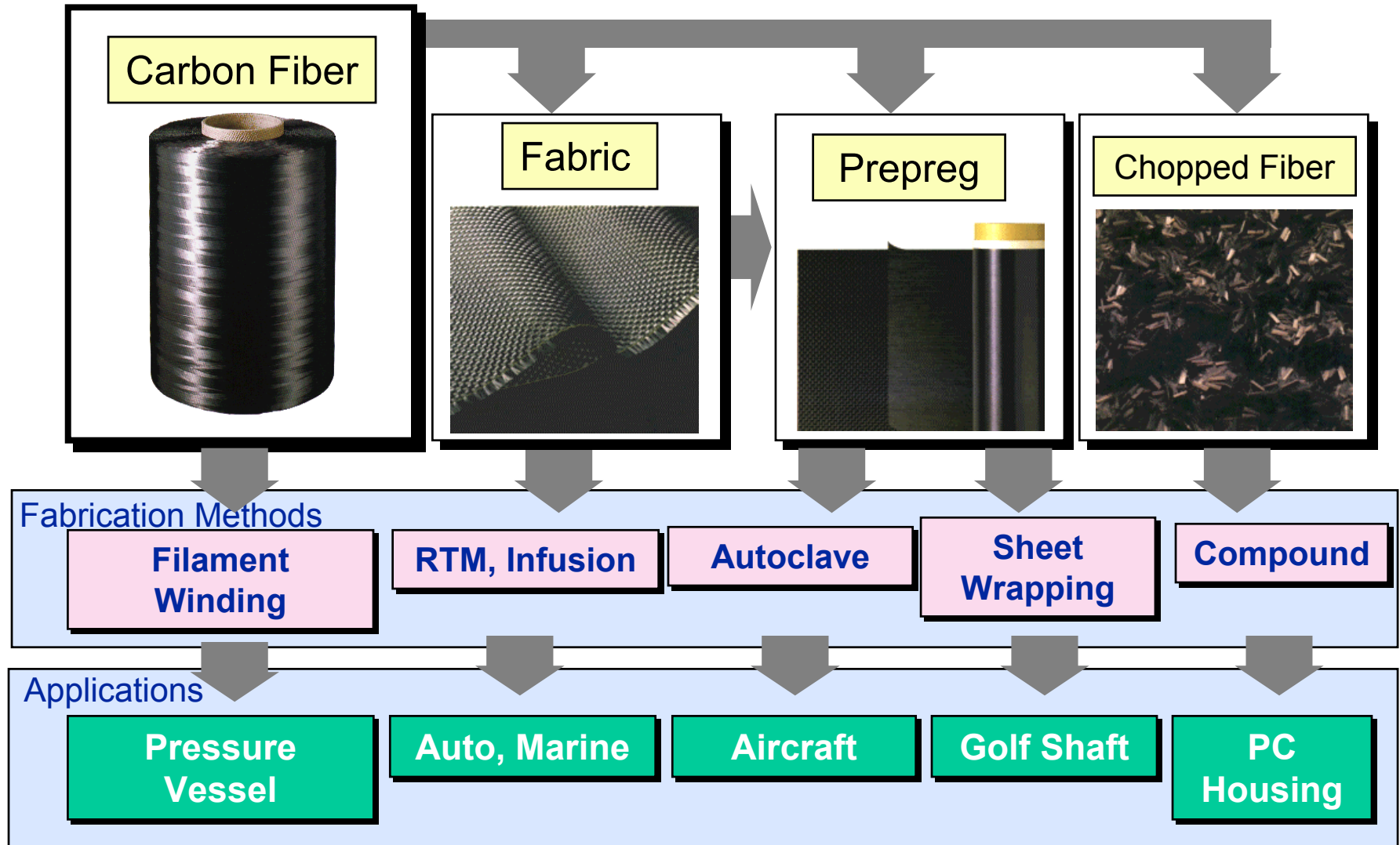
- Strong technical work over the past 30 years
- Focus on new technology to reduce costs and improve performance
- Numerous facilities in Japan
- CFA Technical Center
 - Opened Jan 2004 in Decatur, AL
 - Current capabilities:
 1. Basic materials testing
 2. Analysis (SEM, optical)
 3. Composite fabrication
 - Future capabilities:
 1. CF development line
 2. Other composite fabrication processes as needed



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TORAYCA Carbon Fiber Forms

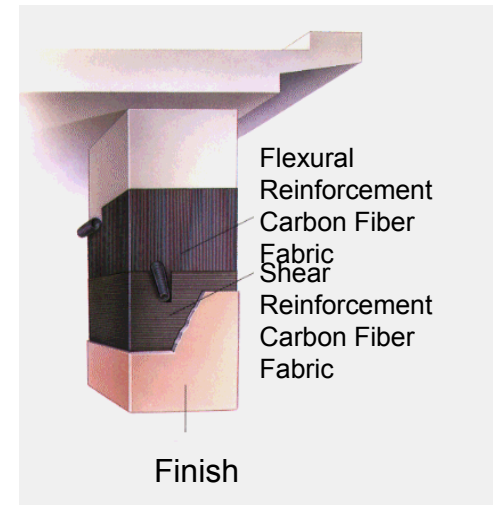


Industrial Applications

- Pressure Vessel
(CNG, SCBA, Hydrogen)
- Civil Eng. & Infrastructure
(Bridge, Construction)
- Marine
(Boat, Sailcloth)
- Energy
(Windmill, Fuel Cell)
- Offshore Oil
(Drill Riser, Tendon)
- Compound
(PC Casing)
- Others



CNG Tank



Civil Engineering



Courtesy: Kockums AB

Marine

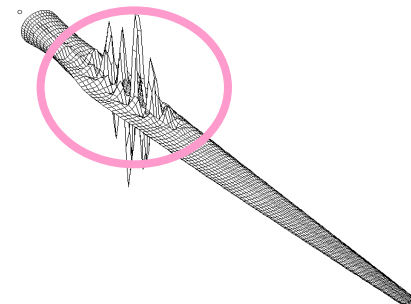


Windmill

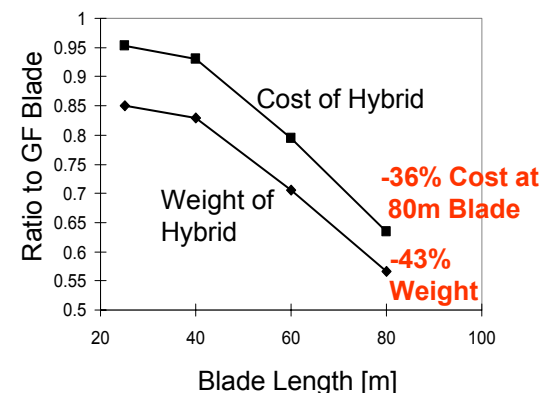
Wind Application

- Industry trend of increasing turbine size (blade length) has recently led to CF becoming economically feasible
- Toray and Soficar supported European market for CF blade development
- A number of companies have announced plans for using CF:
 - Vestas V90 (3.0 MW)
 - NEG Micon NM92 (2.75 MW)
 - DeWind D8 (2.0 MW)
 - Nordex (5 MW)
 - REPower (5 MW) with LM 61.5m blade

Toray FEA Capability



Toray CF Blade Study



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1. Toray Industries and Toray CFA Company Information
2. CF Forms and Applications
3. ***CF Technical Issues for the Wind Market***
 - a. Categories of CF – Aerospace vs. Commercial
 - b. Factors influencing composite properties
 - c. Compression strength of CFRP
4. CF Commercial Issues for the Wind Market

Categories of Carbon Fiber

- Carbon fibers are generally categorized in various groups
 1. Tensile Strength - 500 to over 900 ksi
 2. Tensile Modulus - Standard (33 Msi)
 - Intermediate (40-45 Msi)
 - High (> 45 Msi)
 3. Tow Size - Small tow vs. large tow (1K to 48K)
 4. Sizing Type - Resin compatability
 5. Application - Aerospace vs. commercial
- No industry-wide accepted categories
- Typically, categories do not capture relationship of fiber properties to composite properties

Aerospace vs. Commercial Fibers

1. Performance - Aerospace applications require demanding fiber properties to provide balanced composite properties
2. Qualification - Aerospace testing requirements and lengthy qualification are major cost drivers for aerospace fibers
3. Change Control - Aerospace fibers are under restrictive change control clauses, preventing utilization of cost-down technologies
4. Quality - Both aerospace and commercial applications require high quality standards, including performance and processing. Aerospace has higher quality testing standards.
5. Tow Size - Both aerospace and commercial applications require cost effective fiber forms

Toray products include:

Aerospace: T300, T700G, T800H, T800S

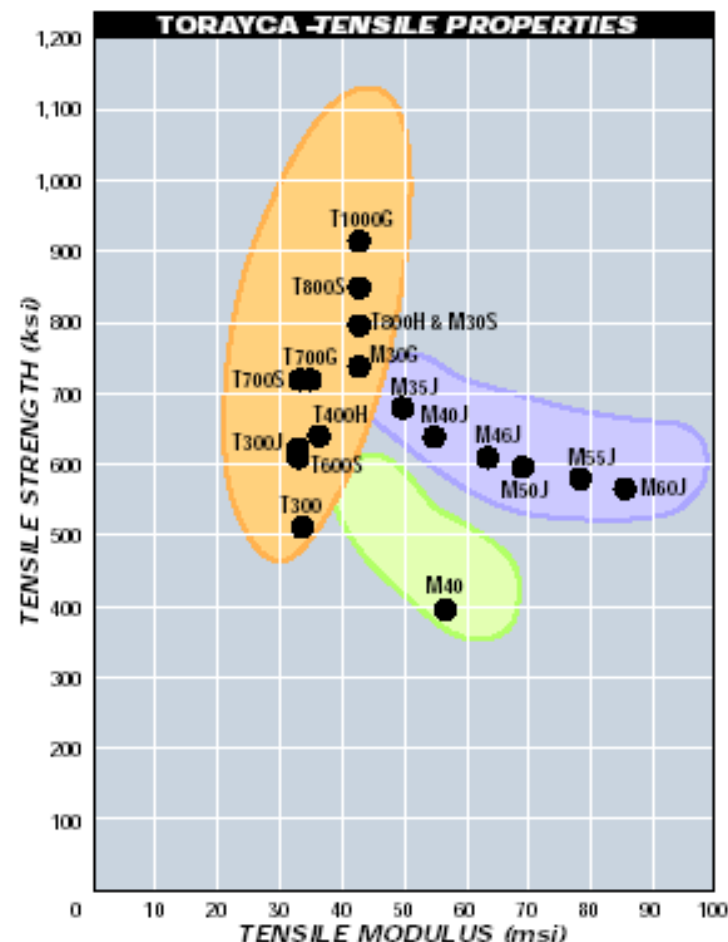
Commercial: T600S, T700S

Aerospace Fibers				
T300				
T700G				
T800H				
T800S				

Commercial Fibers				
T600S				
T700S				
	1K	3K	6K	12K
				24K

TORAYCA Product Information

TORAYCA TYPICAL FIBER PROPERTIES										
FIBER TYPE	Number of Filaments	Sizing Type	Tensile Strength		Tensile Modulus		Elongation %	Yield g/1000m	Density g/cm ³	Standard Spool Size (kg)
			ksi	MPa	MSI	GPa				
T300	1,000	4.5	512	3,530	33.4	230	1.5	66	1.76	1.0
	3,000 ¹⁾	4.5						198		2.0
	6,000 ¹⁾	4.5						396		2.0
	12,000 ¹⁾	4.5						800		4.0
T300J	3,000 ²⁾	4	611	4,210	33.4	230	1.8	198	1.78	2.0
	6,000 ²⁾	4						396		2.0
	12,000 ²⁾	5						800		4.0
T400H	3,000	4	640	4,410	36.3	250	1.8	198	1.80	2.0
	6,000	4						396		2.0
T600S	24,000 ³⁾	5.6	600	4,140	33.4	230	1.8	1,700	1.79	6.0
T700S	12,000 ³⁾	5.6,F	711	4,900	33.4	230	2.1	800	1.80	6.0
	24,000 ³⁾	5.6,F						1,650		6.0
T700G	12,000 ³⁾	3	711	4,900	34.8	240	2.0	800	1.80	6.0
	24,000 ³⁾	3						1,650		6.0
T800H	6,000	4	796	5,490	42.7	294	1.9	223	1.81	2.0
	12,000	4.5						445		4.0
T800S	24,000 ³⁾	1	853	5,880	42.7	294	2.0	1,030	1.80	4.0
T1000G	12,000	4	924	6,370	42.7	294	2.2	485	1.80	2.0
M35J	6,000	5	683	4,700	49.8	343	1.4	225	1.75	1.0
	12,000	5						450		2.0
M40J	3,000	5	640	4,410	54.7	377	1.2	113	1.77	0.5
	6,000 ¹⁾	5						225		1.0
	12,000 ¹⁾	5						450		2.0
M46J	6,000 ¹⁾	5	611	4,210	63.3	436	1.0	223	1.84	1.0
	12,000 ¹⁾	5						445		2.0
M50J	3,000	5	597	4,120	69.0	475	0.8	109	1.88	0.5
	6,000	5						218		1.0
M55J	6,000	5	583	4,020	78.2	540	0.8	218	1.91	0.5
M60J	3,000	5	569	3,920	85.3	588	0.7	103	1.93	0.2
	6,000	5						206		0.4
M30S	18,000 ³⁾	5	796	5,490	42.7	294	1.9	760	1.73	4.0
M30G	18,000 ³⁾	1	739	5,100	42.7	294	1.7	760	1.73	4.0
M40	1,000	5	398	2,740	56.9	392	0.7	61	1.81	0.15
	3,000	4						182		1.0
	6,000 ¹⁾	5						364		1.5
	12,000 ¹⁾	5						728		4.0



- TORAYCA fibers are available in a wide range of properties
- TORAYCA fibers are known for high quality and high performance
- Typical commercial fibers include T600S, T700S and M30S

Composite Properties

- The mechanical performance of composites, on a material level, are greatly affected by many variables, including the following (not limited to):

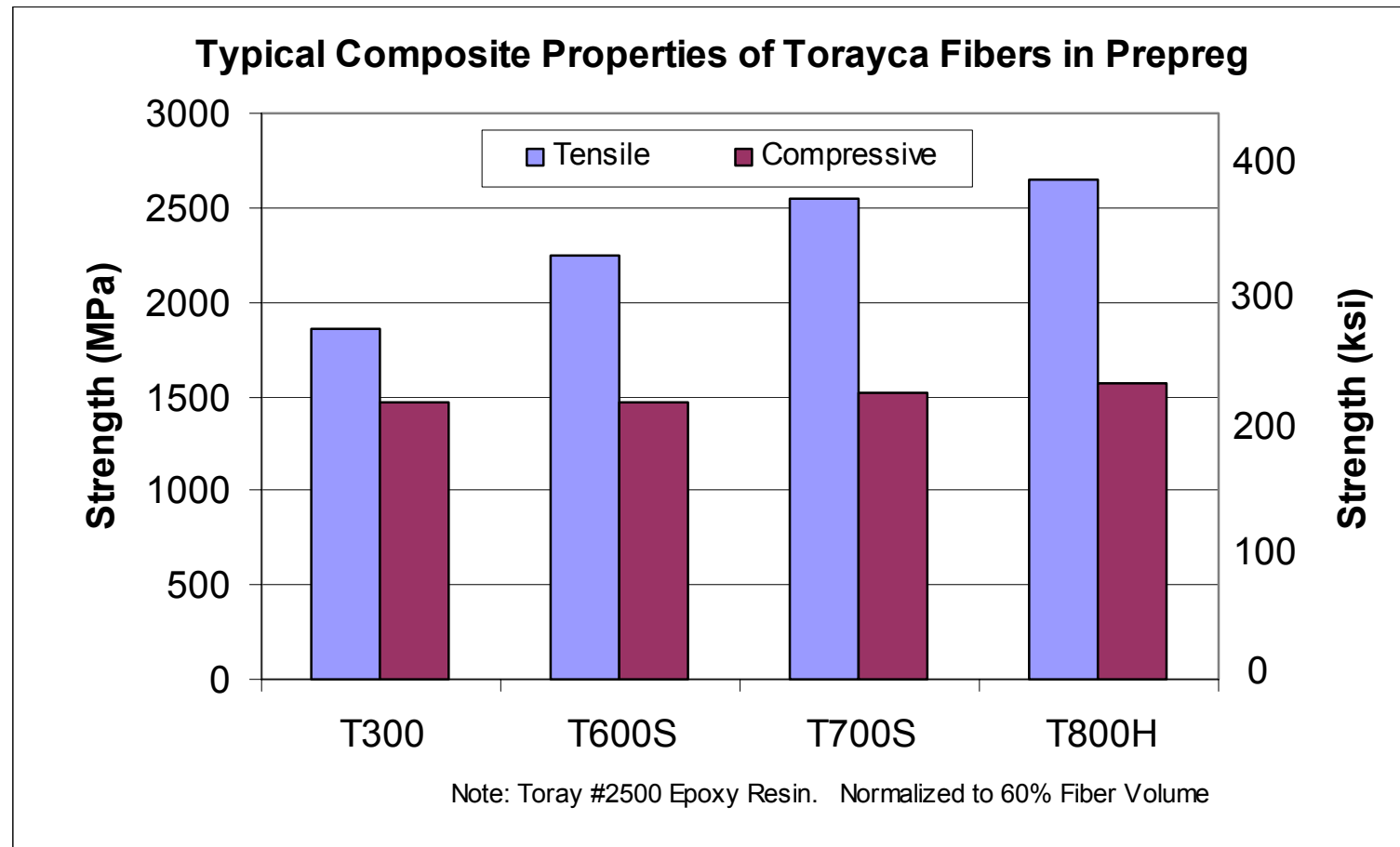
Material

1. Fiber type - Tensile strength, modulus and adhesion characteristic
2. Fiber form - Unidirectional, fabric (stitched, woven), chopped
3. Resin type - Resin strength, modulus, and adhesion

Process

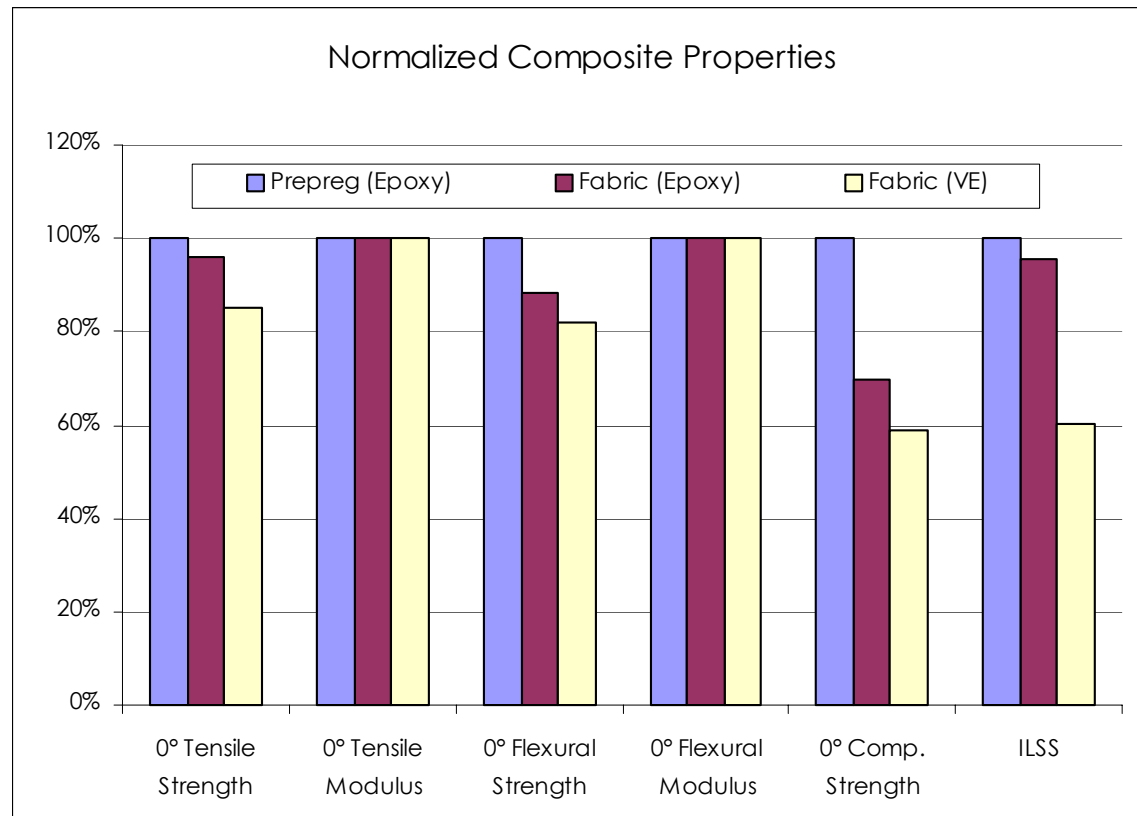
4. Fiber volume and fiber alignment
5. Fiber and resin distribution

Effect of Fiber Type on Composite Properties



- Composite tensile strength is improved with higher strength fibers
- Composite compression strength is not significantly improved with higher strength fibers

Effect of Fiber Form and Resin on Composite Properties



- Data normalized to 55% fiber volume where applicable
- All data tested from unidirectional fiber forms

- Prepreg (UD) form provides best composite properties
- Epoxy resin provides higher properties vs. vinyl ester resin
- Recommend T600S based UD epoxy prepreg for wind market as most cost-effective form

-
- Figure 10 consists of two parts. On the left is a schematic diagram of a circular arch. The arch has a diameter D and a radius A . It is supported at two points, and a horizontal force is applied at the top. On the right is a graph of ϕ/D versus compressive strain ϵ_A (%). The y-axis ranges from 1.3 to 1.4, and the x-axis ranges from 0 to 2. The curve shows a constant stress of 1.34 for strains up to 1.07%, after which the stress increases linearly.

Figure 1 is a scatter plot showing the relationship between fiber compressive strength (σ_{fc}) on the x-axis and composite compressive strength (σ_c) on the y-axis. Both axes are in GPa. The x-axis ranges from 0 to 9.0 GPa, and the y-axis ranges from 0 to 3.0 GPa. Data points for various fiber types are plotted: KF, PEF, Pitch, M46, M40, GF, T300, M30, and T800K. Two theoretical curves are shown: a dashed line representing $\sigma_c = 0.6 \sigma_{fc}$ and a solid curve that fits the data points more closely. The solid curve starts at the origin and increases monotonically, passing through points like M46, M40, GF, T300, M30, and T800K. The dashed line is steeper than the solid curve and passes through points like PEF and Pitch.

Theoretical Compression Strength of CFRP

- Toray conducted low temperature flexural test to access the potential compression strength of CFRP
- Bending strength of T800H was improved to 2.6 GPa (377 ksi) from 1.7 GPa (247 ksi)
- Result can be roughly predicted by modified Rosen's equation:

$$\sigma_c = G_m / (1 - V_f + G_m V_f / G_f)$$

- Improvement due to increase of resin modulus, which improved shear stability
- Higher compression strength of CFRP could be possible with new technology

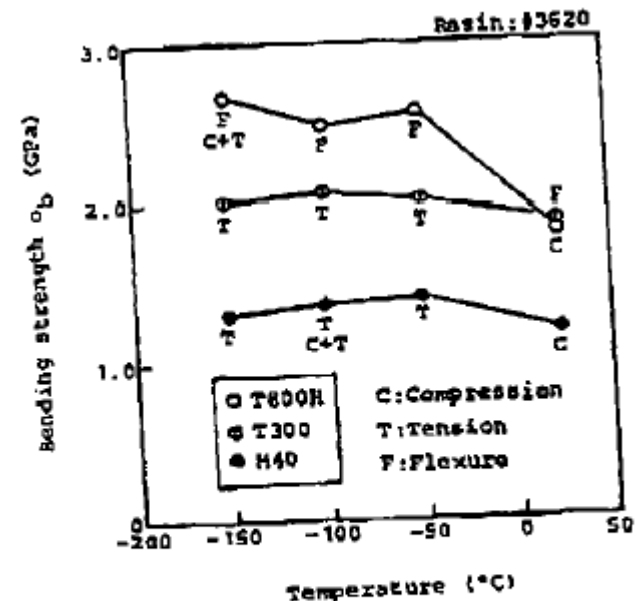


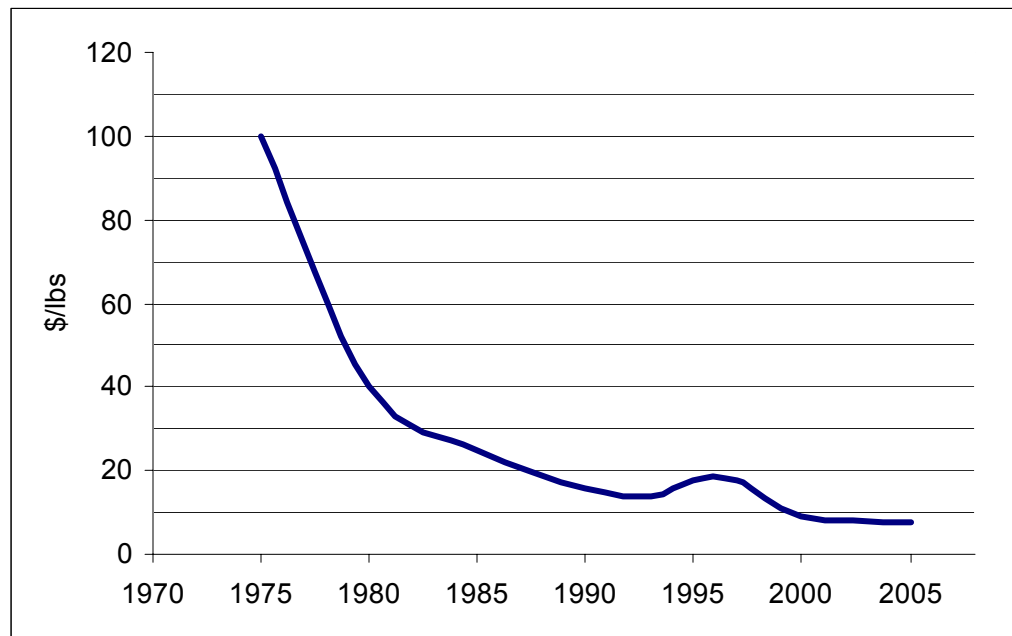
Fig. 8 Bending strength at low temperature conditions for CFRP

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History of Carbon Fiber Price

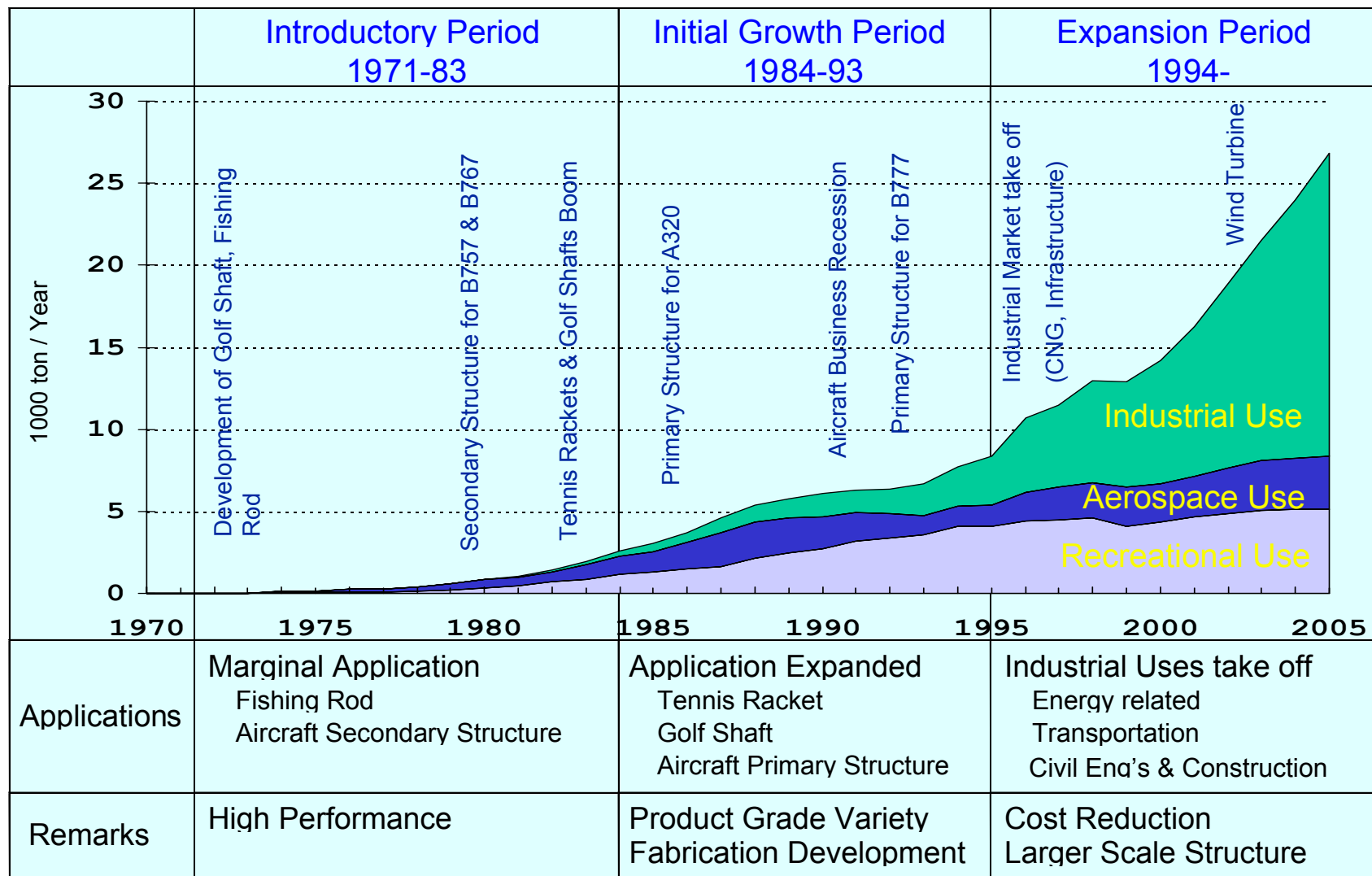
(Non-Aerospace, 24K or less)



Reference: Toray Data and High Performance Composites, July/August 2000

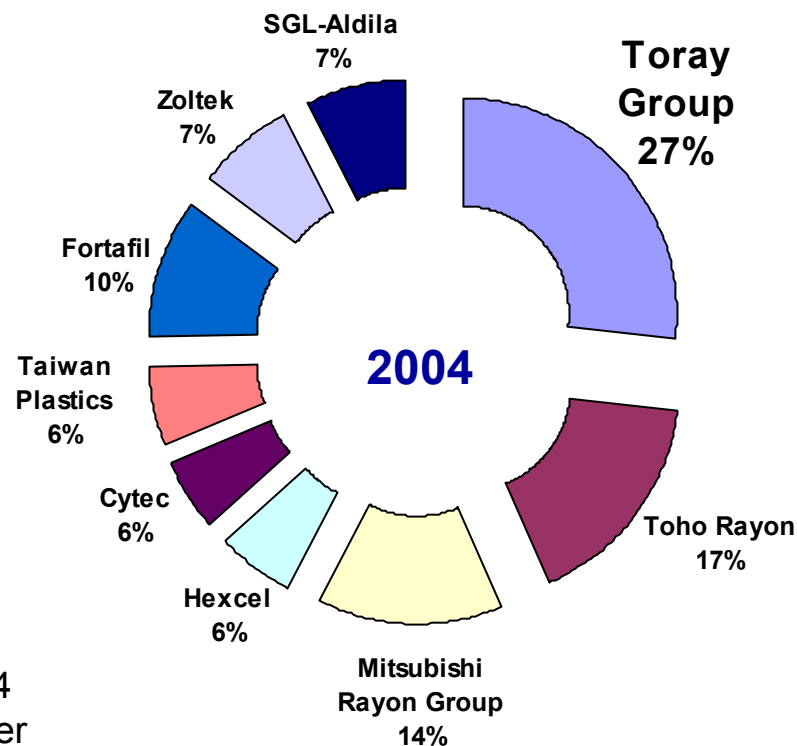
- General long-term trend of lower carbon fiber price over 30 year history
- CF supply-demand and exchange rates effect market price in short-term

History of PAN Carbon Fiber Market



Worldwide PAN Carbon Fiber Capacity

	Tons	M lb.
Toray Group	9,100	20.0
Toho Rayon	5,600	12.3
Mitsubishi Rayon Group	4,700	10.3
Hexcel	2,000	4.4
Cytec	1,900	4.2
Taiwan Plastics	2,000	4.4
Fortafil	3,500	7.7
Zoltek	2,500	5.5
SGL-Aldila	2,500	5.5
Total	33,800	74.4



- Unit: Amount/year - Announced figures by year end 2004
- Large tow CF capacity may be used for oxidized PAN fiber

- Toray is the world's largest PAN CF supplier
- Toray is the only CF supplier to expand in 2004

Future CF Demand from the Wind Market

- Annual installed wind turbine capacities are predicted to be 10-15 GW in 2010
- CF usage estimated at roughly 1 ton/MW (design dependent)
- If...
 - ❑ 25% turbines use CF → 2500-3750 ton CF demand
 - ❑ 50% turbines use CF → 5000-7000 ton CF demand
- Toray's current production machine technology is 1800 ton/yr, the largest in the world
- Toray is committed to support future wind business, provided business feasibility

Summary

1. Toray leading global CF supplier, providing high-quality commercial and aerospace fibers
2. Toray's committed technical focus will further strive to improve performance and reduce costs
3. T600S based UD epoxy prepreg recommended for wind blade application
4. In the future, CFRP compression strength could be improved with new technology
5. Toray's future CF expansion dependent on business feasibility